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Evaluation of the Dynamic Velocity Effect for Steam Generator Wide Range Water Level

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1. Introduction

The measurement of Steam Generator (SG) water level is based upon pressure differential of the level transmitter. As shown in Fig. 1, if the location of a lower tap is in the downcomer region, a deviation between the indicated level and the actual level occurs. This phenomenon is called 'velocity effect' or 'dynamic effect.' This effect needs to be addressed to obtain a more accurate SG water level. Korean Utility Requirements Document (KURD) requires Downcomer Velocity Effect (DVE) to be quantified and to be considered in the instrument requirements. In this paper, DVE occurred through downcomer will be evaluated for SG wide range (WR) level for OPR1000.

2. Methods and Results

In this section, the SG condition is based on the operating steam pressure of 1076 psia, saturation temperature of 553.54˚F, 100% load, and reference leg at 120˚F. The calculated span value corresponds to steam generator fluid levels between the lower tap and the upper tap.

2.1 Calculation for SG WR Level

The normal operating temperature range for the level transmitters is 50~120˚F, and it is most probable that the containment temperature is near the high end due to the large quantities of heat generated by the reactor vessel, SG, and electrical equipment during normal conditions. Also the insulating characteristics of the containment wall will tend to maintain the high end of the normal operating range. Therefore, in calculating the density of the reference leg fluid, it is assumed that the reference leg is at a temperature of 120˚F.

In Fig. 1, SG model is introduced for calculation of WR level. The pressure and density around steam drum are expressed as P_s and ρ_s and distance between taps as H, height between lower tap and level transmitter as E, water level above lower tap as h, distance between lower tap and feedring as H_{feed}, respectively. In the case that h is above H_{feed}, the density of water under the feedring as $\rho_{downcomer}$, above the feedring as ρ_{drum}, the average of the water as ρ_w and fluid density in the reference leg as ρ_{ref}. The unit of h, H, H_{feed} is in inches, density in ft^3/lb, pressure in psia. The fluid level in the condensate pot is at the same height as the bottom of the upper tap. The part above the feedring is filled with water coming from moisture separators. The part under the feedring is filled with the mixture of recirculating water and feedwater, which are in other thermal-hydraulic state respectively. For this reason, the average water density ρ_w is calculated as follows:

When h> H_{feed}, $\rho_w = \dfrac{\rho_{drum}(h - H_{feed}) + \rho_{downcomer} H_{feed}}{h}$

When h< H_{feed}, $\rho_w = \rho_{downcomer}$

The $\rho_{downcomer}$ and ρ_{drum} are the function of SG pressure and the level, which is provided from SG supplier. Assuming static condition for downcomer fluid, the pressure on the SG WR level transmitter's variable leg side(P_{var}) and on the reference leg side(P_{ref}) are as follows:

$$P_{var} = P_s + \rho_s(H - h) + \rho_w h + \rho_{ref} E \quad (1)$$

$$P_{ref} = P_s + \rho_{ref} H + \rho_{ref} E \quad (2)$$

By equations (1) and (2), the differential pressure of the level transmitter is as follows in psi :

$$\Delta P_T = P_{ref} - P_{var} = \rho_{ref} H - \rho_s(H - h) - \rho_w h \quad (3)$$

And the differential pressure converted in inches head of water at 60˚F is

$$\Delta P_T = \frac{1}{62.383}\left[H(\rho_{ref} - \rho_s) - h(\rho_w - \rho_s)\right] \quad (4)$$

From equation (4), the water level in the steam generator is

$$h = \frac{H(\rho_{ref} - \rho_s) - \Delta P_T \times 62.383}{\rho_w - \rho_s} \quad (5)$$

The SG WR level in %span normalized by $\frac{h}{H} \times 100$ is

$$\%\ WR = \left[\frac{H(\rho_{ref} - \rho_s) - \Delta P_T \times 62.383}{H(\rho_w - \rho_s)}\right] \times 100 \quad (6)$$

Where ρ_s is the steam density in the steam drum region and ρ_w is average density as above. Equation (6) can be applied from hot standby condition to 102% reactor power, so the SG condition from shutdown cooling to hot standby condition should be re-applied to the equation. Strictly, the supplier's density data based on Mass Balance and Momentum Balance is not exactly identical to the actual condition.

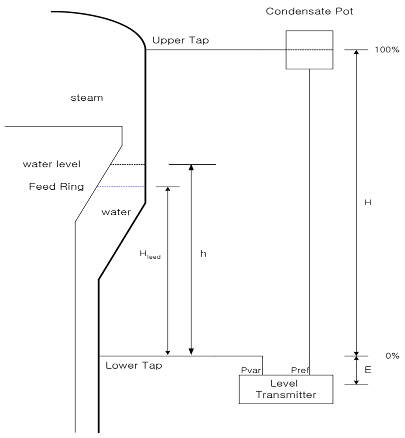

Fig. 1. Steam Generator Model

2.2 Calculation for Dynamic Velocity Effect

SG WR level covers a broad measurement range around 450 inches that the upper tap locates at steam drum region and the lower tap at downcomer region. Because of this, DVE is caused by the fluid velocity difference between the two regions inducing the pressure drop. Assuming the average velocity in the downcomer as V ft/sec, the pressure on the variable leg side is decreased as dynamic pressure and pressure loss comparing with static condition of equation (1). P_{var} according to Bernoulli's equation is

$$P_{var} = P_s + \rho_s(H-h) + \rho_w h + \rho_{ref}E - \frac{\rho V^2}{2g_c} - \left(f\frac{L}{D}+K\right)\frac{\rho V^2}{2g_c} \quad (7)$$

Or

$$P_{var} = P_s + \rho_s(H-h) + \rho_w h + \rho_{ref}E - \left(1+f\frac{L}{D}+K\right)\frac{\rho V^2}{2g_c} \quad (8)$$

The pressure on the reference leg side P_{ref} stays unaffected. The differential pressure for the level transmitter is

$$\Delta P_T = \rho_{ref}H - \rho_s(H-h) - \rho_w h + \left(1+f\frac{L}{D}+K\right)\frac{\rho V^2}{2g_c} \quad (9)$$

Comparing equations (9) to (4), the ΔP_T is increased as much as the DVE expressed in $\left(1+f\frac{L}{D}+K\right)\frac{\rho V^2}{2g_c}$. In case of existing flux in downcomer, the indicated level is lower than actual level by the DVE according to equations (5) and (6).

2.3 Consideration for Dynamic Velocity Effect

The SG WR level is used for plant protection signals such as SG low level reactor trip. From equation (9), DVE arisen in SG WR level is determined from variety of physical variables such as flow and level depending on density and velocity, which makes it impossible to determine SG WR level on every single plant condition. So, SG WR level should be adjusted as much as DVE for precise level measurement and indication. To quantify the DVE at every condition requires fluid density and flow data at every condition accordingly. DVE also includes the Friction Effect which is induced by the flow and force deviation in the downcomer region.

The deviation between indicated level and actual level by DVE is evaluated as uncertainty factor and it is most conservative at 40% reactor thermal power for reading of indication and recording. This value is the representative value as DVE applied algebraic sum in uncertainty calculation. Table I shows the differences between indicated level and actual level.

Table I: Indicated Error vs Actual Level

Power Level	**Normal Level Approx 79%**	**Low Level 40%**
120%	-1.88%	
100%	-2.99%	+0.018%
		-0.21%
80%	-4.13%	
60%	-5.62%	
40%	-6.43%	-0.92%
		-0.51%
20+%	-5.69%	
20-%	-5.78%	
0% Isothermal Condition	0%	0%

3. Conclusion

The negative DVE is excluded in SG low level reactor trip setpoint calculation because of conservatism. But its influence on SG high level reactor trip setpoint should be considered. In case of OPR1000, the SG high level reactor trip setpoint excludes SG wide range level because it considers SG narrow range level which measures the SG level over the downcomer region. For Westinghouse type plants, only SG narrow range level affects to both SG high level reactor trip and low level reactor trip, so the DVE should be considered for SG high level reactor trip signal.

For indication and recording, the DVE shows the error between actual and nominal level exists and should be adjusted the nominal value by compensating for the amount of negative DVE.

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